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I, JANENE PEISKER, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. 2002952566 for a patent by DSPACE PTY LTD as filed on 07 November 2002.

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Twentieth day of November 2003

JANENE PEISKER
TEAM LEADER EXAMINATION
SUPPORT AND SALES

AUSTRALIA

Patents Act 1990

PROVISIONAL SPECIFICATION

Invention title: **PILOT SYMBOL PATTERNS IN COMMUNICATION SYSTEMS**

The invention is described in the following statement:

The invention may broadly be said to consist in a method of placing pilot symbols in a data stream for wireless communication, wherein the symbols are spaced in time using a range of different intervals. Preferably the intervals are approximately fractal in nature.

The invention also consists in a signal processing device that generates a data stream or wireless signal having pilot symbols spaced with a range of predetermined intervals. The invention also consists in a signal having pilot symbols of this general kind. Other details of the device and signal will be known to a person skilled in the art and need not be described at this stage.

The invention may also be said to consist in any alternative combination of features that are described or shown in this specification. Known equivalents of the features are deemed to be included whether or not they are specifically stated.

The invention is computationally efficient when compared to random PS data streams. As the Fractal PS have a mathematical relationship with each other, they are predictable, and sufficiently unevenly spaced to perform their intended function of improving the signal to noise ratio, whilst keeping the computational power significantly less than that required for randomly distributed PS schemes.

The Prior Art uses both Unique Words (UW) AND Pilot Symbols to determine and achieve the following functions:

a) Signal Acquisition (which requires coarse timing estimate and a frequency)

b) Calculation of the right frequency

Whereas the invention preferably uses only Pilot Symbols alone (i.e. no UW) to perform both functions a) & b) above.

The current invention lends itself to a system capable of performing both functions (Signal Acquisition & Frequency determination) using PS alone and have superior Packet Error Rate performance using less "overhead" data, thus improving the effective throughput data rate. A reduction in SNR allows lower signal power or greater symbol rate, while the broad bandwidth allows cheaper pre-processing of the incoming data.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The acquisition routine must find the frequency and time that a packet is received. The Unique Word method (UW) transmits a known data stream to assist with the task.

In noise, the frequency cannot be found perfectly. There is an uncertainty principle called the Cramer Rao Lower Bound (CRB) that limits the precision of the frequency. So a short UW at the head of a transmission is not precise enough. Phase drift over time, caused by frequency errors, can cause loss of information.

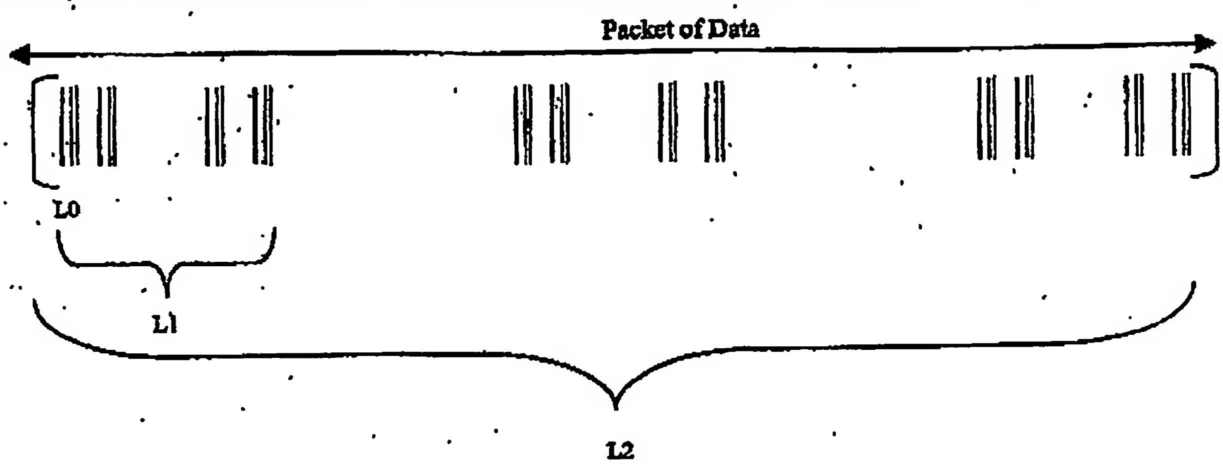
One suggestion is to have two UW's, one at the front and one at the end of the packet. This is precise enough, but not always accurate. Each UW gives a coarse frequency estimate, while the phase difference between the two gives a fine resolution. However, the phase difference is ambiguous by multiples of 2pi, so the fine frequency is also ambiguous. A method, called TurboSynch, forms a list of the possible options, and tries each frequency in turn.

If we had information halfway through the packet, a phase difference of 2pi between the UW's would be obvious, since the halfway point would be wrong by pi radians. It would take a larger frequency offset, with 4pi between UW's, before the halfway point did not help.

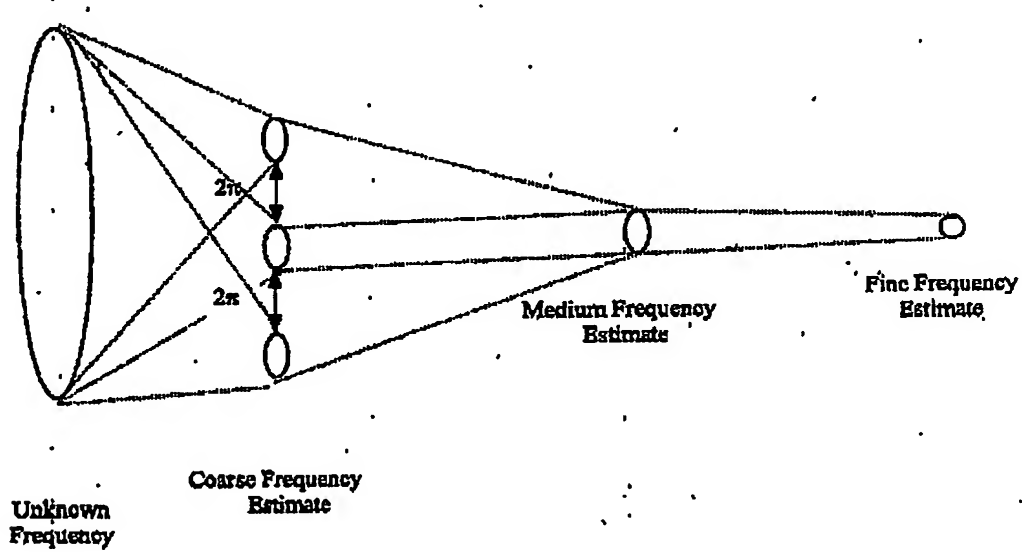
The trouble with two UW's is that we have no information on intermediate length-scales to distinguish between the possible frequency options. A structure with information on all length-scales is a fractal. We now present a UW based on a fractal.

The UW's described above were formed from blocks of pilot symbols (PS). The UW described below has PS's placed irregularly throughout the packet. The pattern has information on all length-scales, so it can resolve ambiguities, but also the pattern repeats regularly enough to deal with noise in a methodical way. A third advantage of using PS throughout the packet is to track the fading reliably.

Placement of Pilot Symbols (PS) within a Packet of Data. Each line represents a symbol.



L0 represents a group of Pilot Symbols, as does L1 and L2



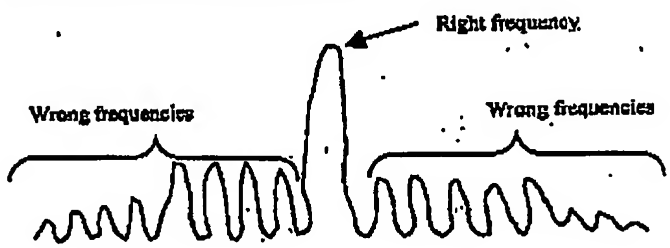
The Acquisition process begins with an approximation of the Medium Frequency Estimate (using the L1 group) followed by the Coarse Frequency Estimate (using the L0 group), and then the Fine Frequency Estimate (using the L2 group).

Principles

- Estimate Coarse Frequency using Pilot Symbols within the same L0 group.
- Estimate Medium Frequency using Pilot Symbols within the same L1 group, however must resolve 2π ambiguities.
- Estimate Fine Frequency using all Pilot Symbols (PS) within the same L2 group.

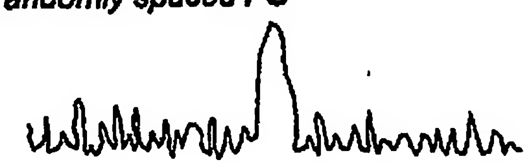
Frequency Response of 2 contiguous blocks of PS.– Prior Art

Frequency Response of Invention (Fractal PS)



"Desired Frequency Response"

Frequency Response of randomly spaced PS



The next account describes the process and steps toward acquisition.

In the following text the terms for:
"TREAT" means to algorithmically summate (or add together)
"USE or USING" means to apply phase correction factor determined from earlier.

These are the Steps to make Pilot Symbols coherent and achieve the Desired Frequency response shown above.

STEP 1

TREAT PS in same L0 as coherent in phase.
TREAT PS in different L1 as independent in phase.
ESTIMATE Phase Differentials on the L1 scale /level.

STEP 2

TREAT PS along each L1 group/level as coherent in phase USING the results in STEP 1.
TREAT PS in different L1 as independent in phase.
Estimate phase differential on L0 scale/level.
USE this to resolve 2π ambiguities from STEP 1.

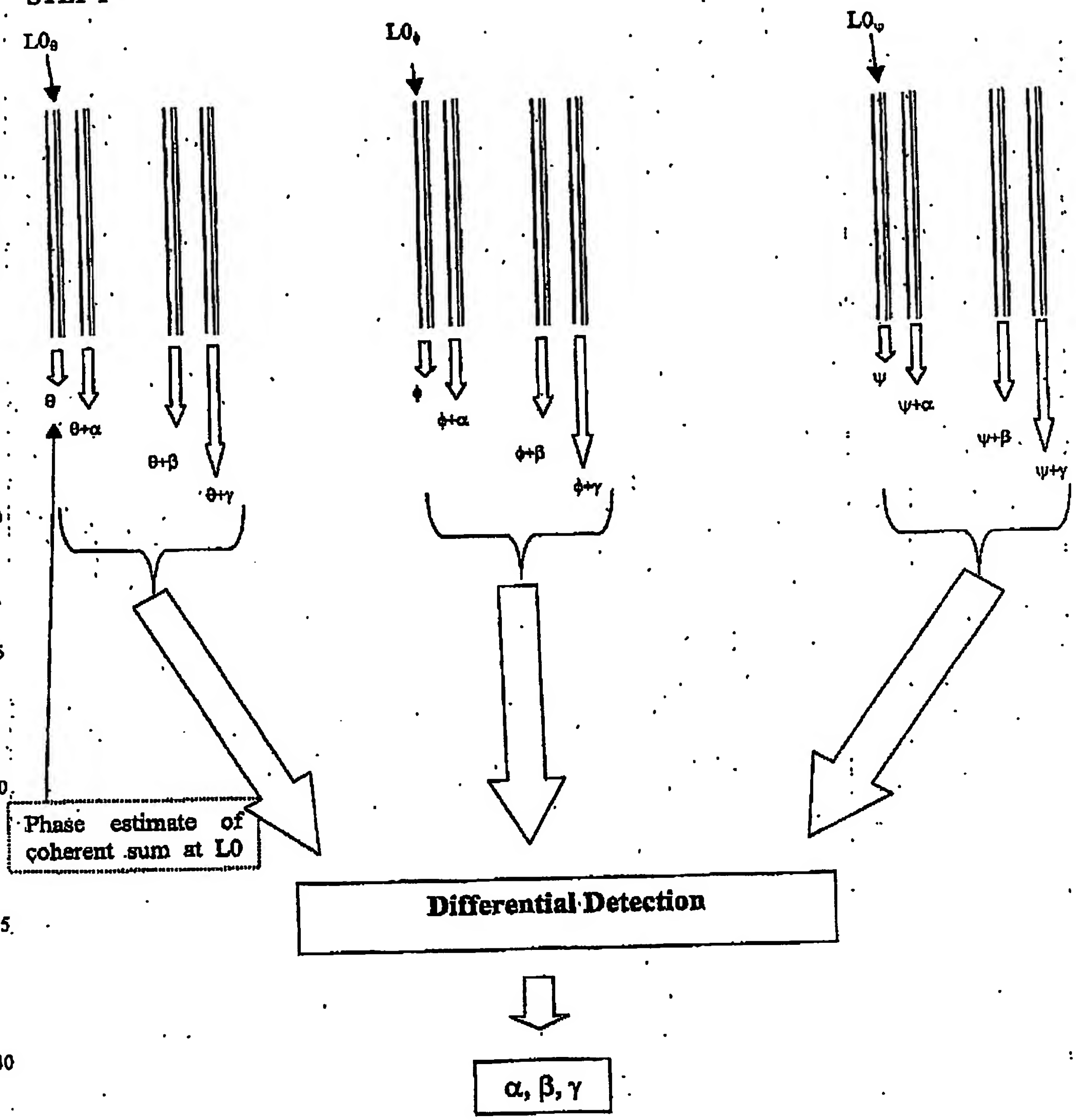
STEP 3

TREAT PS in same L1 as coherent in phase USING the results of STEPS 1 and STEPS 2.
Estimate phase differentials on L2 scale/level.
USE results of STEP1 & 2 to resolve 2π ambiguities to compute a Frequency.

STEP 4

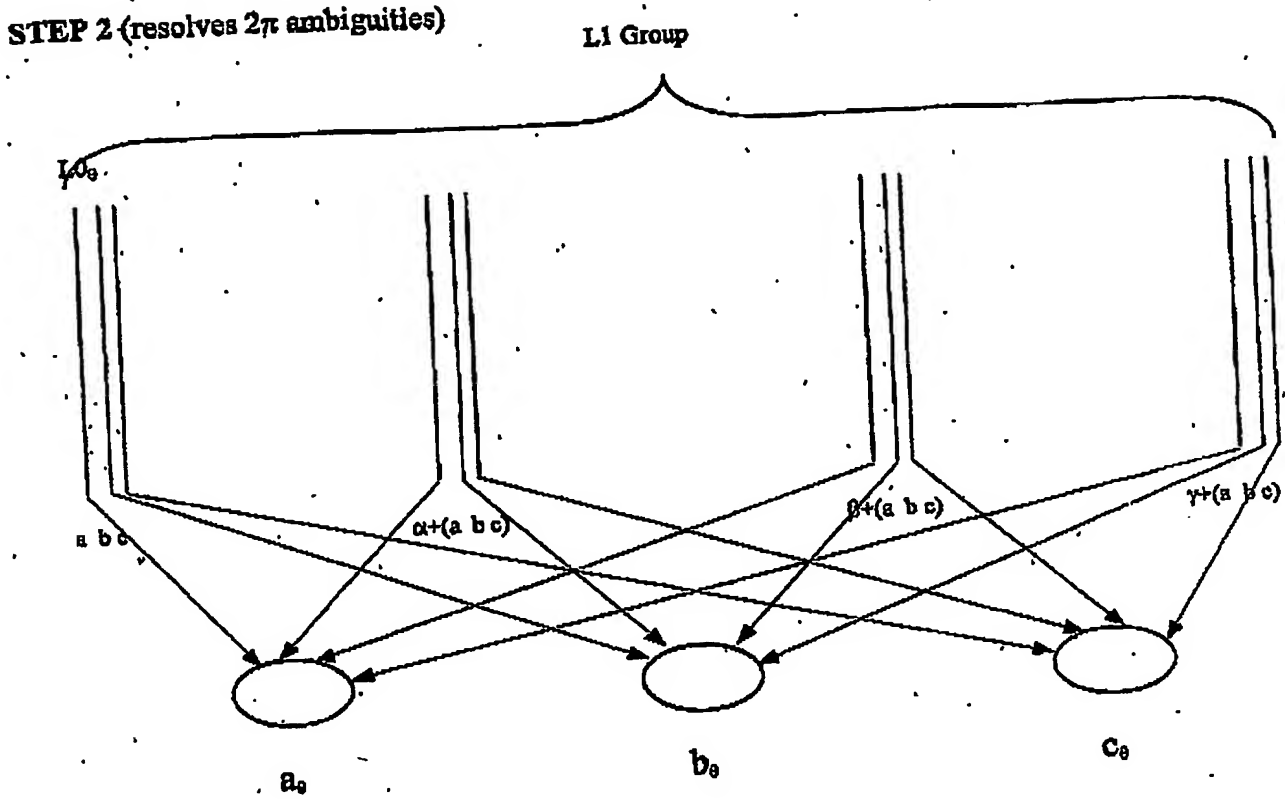
Strip the Frequency found in STEP 3 from all symbols in the packet.
Sum the Pilot Symbols coherently in order to estimate the signal amplitude of the Frequency computed in STEP 3.

STEP 1



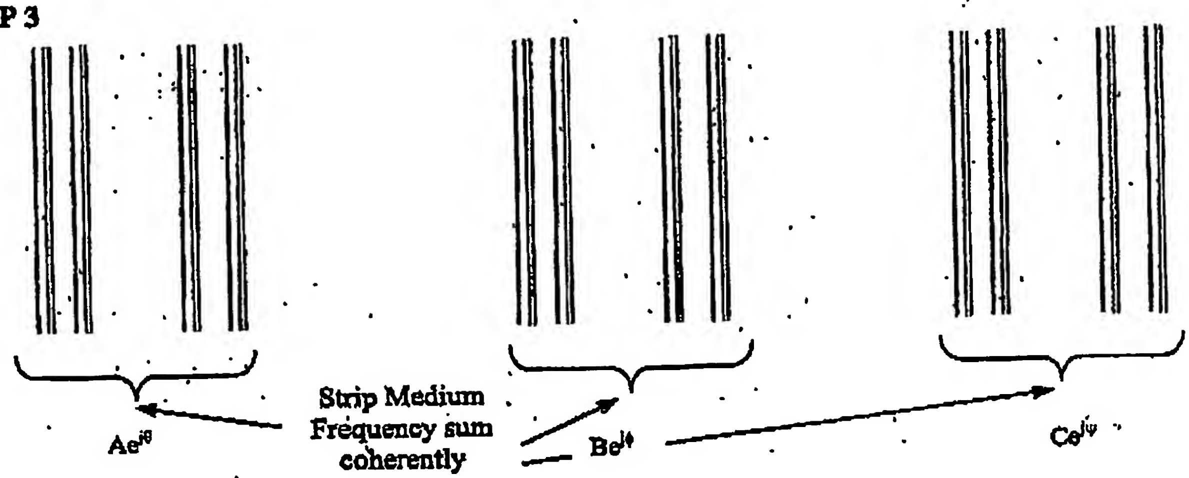
Outcome: Phase Differences between L0 groups within each L1 group. However, the outcome may contain 2π ambiguity.

STEP 2 (resolves 2π ambiguities)



Repeat for ϕ and ψ
Outcome produces phase differences a, b & c. and resolves 2π ambiguity in α, β, and γ.

STEP 3

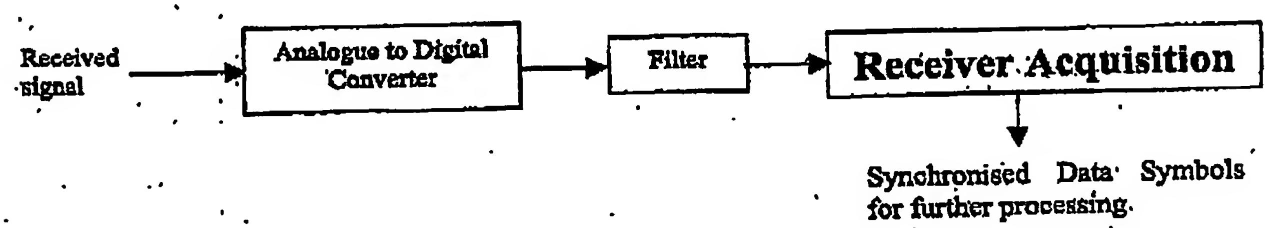


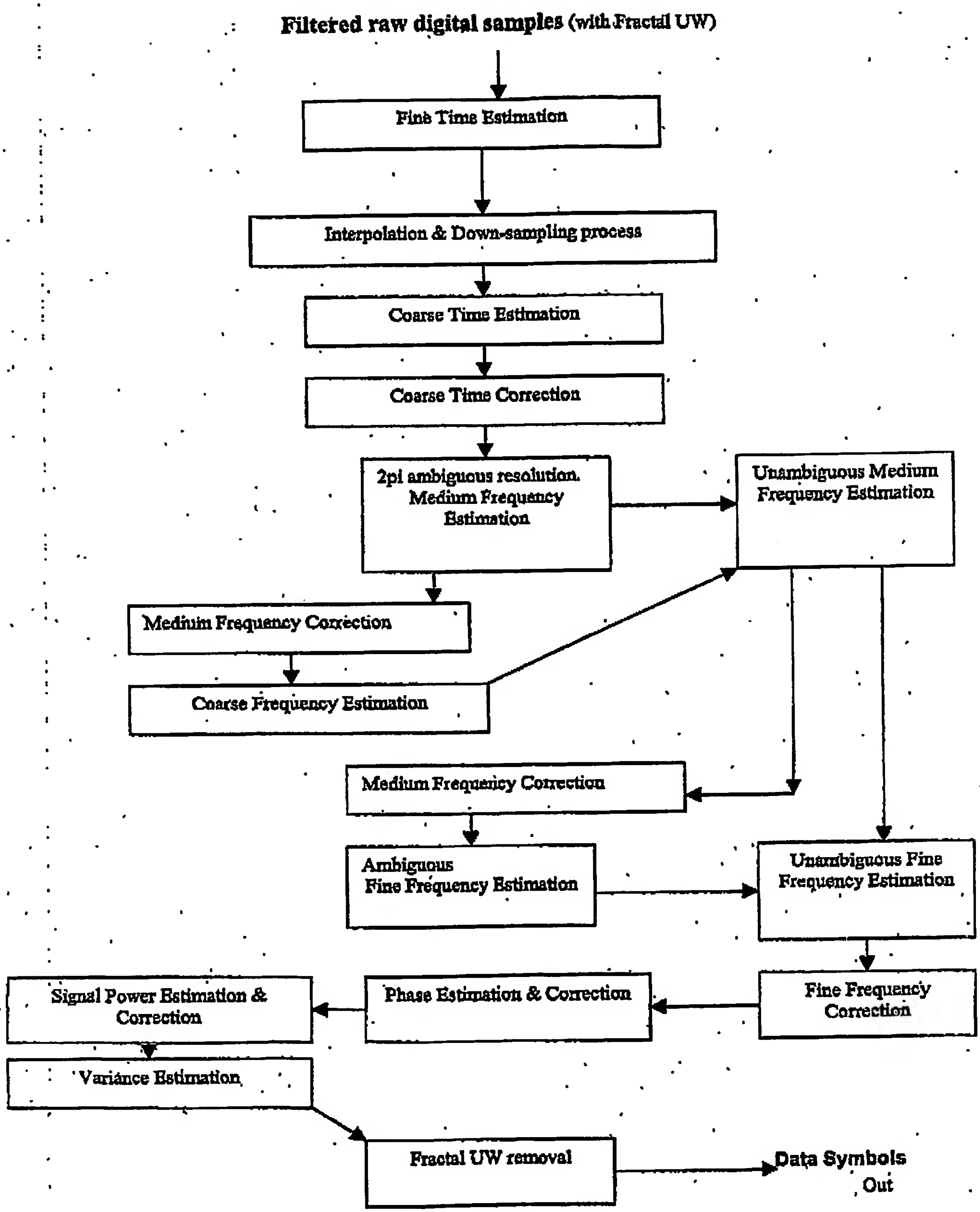
Use $Ae^{j\theta}$, $Be^{j\phi}$, $Ce^{j\psi}$ to estimate the phase differences between L1 blocks. Use these phases to improve the "medium resolution" frequency to yield a "fine resolution" frequency.

STEP 4

Strip the Fine Frequency estimates fro the Pilot Symbols. Sum the resulting values coherently to assist in estimating the signal amplitude. If the signal amplitude surpasses a threshold level, strip the fine frequency estimate from the data symbols. Then output them from the "acquisition routine".

A system block diagram and a flow chart outlining receiver acquisition according to the preferred embodiment are included below.




Filtered raw digital samples (with Fractal UW)
Fine Time Estimation
Interpolation & Down-sampling process
Coarse Time Estimation
Coarse Time Correction
2pi ambiguous resolution. Medium Frequency Estimation
Unambiguous Medium Frequency Estimation
Medium Frequency Correction
Coarse Frequency Estimation
Medium Frequency Correction
Ambiguous Fine Frequency Estimation
Unambiguous Fine Frequency Estimation
Fine Frequency Correction
Phase Estimation & Correction
Signal Power Estimation & Correction
Variance Estimation
Fractal UW removal
Data Symbols Out

To determine the Fractal placement of the Pilot Symbols

1. Choose patterns on each scale or group (L0, L1, L2, ...) to minimise the frequency response of the "wrong frequencies".
2. The actual fractal pattern depends on the overall length of the packet, therefore is scaleable for different Packet lengths.
3. The actual fractal pattern depends on the total number of Pilot Symbols within a Packet.
4. The actual fractal pattern depends on the frequency bandwidth under consideration.

All the above give rise to different patterns of Pilot Symbols actually chosen and implemented.

Prior Art Techniques – Packet Error Rate performance

The Prior Art uses Unique Words (UW) plus Pilot Symbols (PS) to assist in the acquisition and Frequency determination of the data stream and thus includes an "overhead" to the real data being transported. The current invention performs 0.5db – 1.0db better (in terms of acquisition Packet Error Rate) when compared to the prior art using the same number of PS plus UW overhead. That is to say, for a given number of PS (only) as overhead, the invention has superior performance, by 0.5db – 1.0db.

Implementation efficiency

The implementation issues are:

- Maintaining low manufacturing costs through low cost computational powered digital processing integrated circuits. (i.e. lower priced DSP, Microprocessor, FPGA or other related computing integrated circuits.)
- Maintaining or improving on the high performance in packet error rate figures
- Maximising the effective data rate throughput by maintaining or lowering the "overhead" data.

The current invention has benefits in producing a data delivery system with reduced manufacturing costs, AND a system with high performance AND low data overheads.

Application of the System

This invention or system of applying Fractal PS can be applied to sub-carrier based modulation systems (eg. OFDM) and TDMA Systems.
In addition, the methods described apply to block-based estimators for short-packet sized data streams and sliding-window estimators for long-packet or continuous transmission data streams.

DETAILED EXAMPLE OF A PACKET STRUCTURE

400 Symbols
36 Pilot Symbols
Frequency offset up to 5 percent of the symbol rate
-> Bandwidth F = 2*5% = 10% of symbol rate

The number of levels in the structure depends on the number of pilot symbols. This embodiment has three embodiment has three levels, but fewer or more are possible. This embodiment has three Pilot Symbols per L0 block, three L0 blocks per L1 block and four L1 blocks in the full L2 block, for a total of 36 Pilot Symbols in the packet. The scale factor at each level should be ideally between 3 and 6, and the product of the scale factors equal the total number of Pilot Symbols allowed.

The acquisition process finds it easier to distinguishing Coarse-Time (CT) offsets than to distinguish frequency offsets. The CT acquisition performs early stages of the frequency acquisition, repeated for several different time-offsets. Making the early stages faster speeds up the acquisition. An L1 block with few Pilot Symbols is quicker to calculate than one with more Pilot Symbols, so this embodiment speeds the whole acquisition algorithm by choosing small scale-factors for L0 and L1 in the paragraph above.

Each L0 block has its Pilot Symbols at positions
(n, n+1, n+3).
Each L1 block has its L0 blocks starting at positions
(m, m+7, m+19).
The L1 blocks start at positions
(k, k+60, k+240, k+360)

Fine Structure
The first step in the algorithm assumes the symbols within each L0 block are coherent. There is a frequency offset of up to 1/20 cycle per symbol, so an L0 block should not cover more than four symbols. The L0 should be as long as possible subject to that restriction because a longer L0 block will give a better coarse frequency estimate than a shorter L0 block. For these reasons, the positions (n, n+1,n+3) were chosen for the L0 structure. That is, if an L0 block starts at position n, then symbols at positions n, n+1 and n+3 will be Pilot Symbols. This will let the Pilot Symbols distinguish between frequencies that are separated by a large amount.

Medium Structure
The L1 pattern contains three L0 blocks. It should be wide enough to give a moderately precise frequency estimate, but the L0 blocks should be close enough, and spaced unevenly, so that all wrong frequencies, within scope of the coarse frequency estimate, give a weak response when compared with the correct frequency. This embodiment places the L0 blocks starting at symbols (n, n+7, n+19). This lets the Pilot Symbols distinguish between frequencies that are separated by a moderate amount.

Coarse Structure

The full L2 pattern contains four L1 blocks. The full width of the L2 should cover most of the packet, as a longer L2 allows more precise frequency estimation. These L1 blocks should be spaced unevenly, in a way that all wrong frequencies within scope of the medium frequency estimate, gives a weak response. This embodiment places the L1 blocks starting at positions n,n+60, n+240 and n+360. The reason for this choice was so that L1 block-pairs exist that are separated by 60,120,180,240,300 and 360 symbols. This range of distances makes the Pilot Symbols pattern effective at distinguishing finely between possible frequencies.

Metric for selecting symbol pattern

Suppose a pattern of Pilot Symbols has been chosen. This section describes a quick way to evaluate it. The operator can then, given the number of pilot symbols and the packet length, evaluate a wide range of potential fractal patterns.

Take a vector that represents a packet of data, one entry per symbol. Place a 1 in each entry that represents a Pilot Symbol, and a zero in the other entries, that represent Data Symbols.

Obtain the frequency response by taking the vector's Fourier Transform. Restrict this FT to frequencies within the specified Frequency Bandwidth (here $F = 2x5\% = 10\%$) of the zero frequency. The Correct Frequency in this case is zero, and that Fourier coefficient will be strongest. The second-highest Fourier coefficient, within the Frequency Bandwidth F of the zero frequency, is the most likely to cause a frequency error. Let R be the ratio between the first and second Fourier Coefficients

R = abs (Strongest Fourier Coefficient) / abs (Second-Strongest)

The higher this ratio R, the better the pattern is for acquiring the signal frequency.

The following symbol positions are chosen to place 36 Pilot Symbols within a 400-symbol packet.

10 + [0,1,3,7,8,10,19,20,22,
60,61,63,67,68,70,79,80,82,
240,241,243,247,248,250,259,260,262,
360,361,363,367,368,370,379,380,382]

DETAILED ANALYSIS OF ERRORS

The invention uses an approximately fractal Unique Word. An algorithm for time and frequency acquisition is suggested and analysed.

Definition of Fractal UW

The UW includes an irregular collection of samples. Their indices within the packet are

$$a\_\{ijk\} = iq + pv[j] + w[k]$$
$$\text{for } i = 1..C,\ j = 1..M,\ k = 1..F$$

There are C*M*F Pilot Symbols (PS) in the Unique Word (UW).

The vectors v and w are irregularly spaced integers. For example,

$v = [0,1,5,8,10]$
$w = [0,1,4,6]$
$p = 9$ ** this might change for 20ms packet **
$q = 100$
$C = 6$ large groups
$M = 5$ small groups per large group
$F = 4$ PS per small group

The UW may also have BPSK values,

$$UW\_\{ijk\} = P(i)\,Q(j)\,R(k)$$

where P(i),Q(j) and R(k) are chosen from +/−1 and the vector P has low autocorrelation.

On a fine scale, the PS's have a pattern given by the vector w. On an intermediate scale, groups of F PS's are arranged in a pattern given by the vector v, on a scale that is p times larger. On a large scale, the groups of F*M PS's are spaced evenly along the packet, to allow the fading to be tracked.

The analysis will also involve the following numbers :

σ^2 = AWGN power / Signal Power
$F_2 = F(F-1)/2$
$M_2 = M(M-1)/2$

Technique :

1. For a given time offset, select the samples that would make up the UW. Strip the BPSK UW values from them.
2. Sum all symbols within each smallest group. This will diminish the noise by say 5dB, depending on the UW and on the frequency offset.
3. Use differential decoding to get a medium-resolution frequency estimate with moderate ambiguity problems. In this step, the fine time offset is also found.

4. Strip the medium frequency estimate from the UW symbols. Apply steps similar to 2 and 3 to yield a coarse-resolution frequency with negligible ambiguity problems.
5. Combine the medium and coarse frequency estimates to give an ambiguity-free, medium resolution frequency.
6. Strip this frequency from the UW. Sum symbols coherently within each medium-sized group. This will diminish the noise further and allow estimation of a fine frequency. Use the medium frequency to resolve the ambiguity in the fine frequency.
7. Track the phase and power through the packet using a moving average of the PS.

Analysis

There are six sources of error;

a) Incorrect Fine Time.
b) Wrong frequency chosen for medium frequency.
c) Wrong frequency chosen for coarse frequency.
d) Wrong ambiguity chosen when combining medium and coarse frequencies.
e) Wrong frequency chosen for fine frequency.
f) Wrong ambiguity chosen when combining medium and fine frequencies.

There is also a degradation caused by the initial frequency offset and by intermediate frequency estimation errors.

The variance in frequency will then be estimated assuming that none of the six errors occur.

The PS within each small group, and the small groups within each medium group are assumed spaced in a specific irregular manner. The medium groups will be placed evenly within the packet to allow the fading to be tracked.

Clarification of Error Sources

The incorrect Fine Time is self-explanatory.

When a frequency is estimated using a short FFT, the frequency may either be off by a little, as the local maximum is shifted, or it may be off by a lot when the wrong Fourier coefficient is chosen. See Figure 1. Errors d) and f) are caused by errors of the former type; errors b), c) and e) are errors of the latter type.

The coarse frequency estimate is used to resolve ambiguities in the medium frequency estimate. However, since there is a variance in both estimates, there is a chance that the wrong ambiguity will be chosen, giving errors of type d) and f).

In several places, data symbols are added as if they were coherent. Any frequency offset causes a temporary loss in signal to noise ratio and 'permanent' loss in probability of acquisition.

Concrete formulae

The formulae used to estimate the fine time and variance are given in this section. Their variances and likelihood of error will be found in the next section.

Let the data stream be u_t, where t is measured in units of the symbol rate. So samples happen at quarter-units.

s_{ijk;t} = u_{qi+pv(j)+w(k)+t} are the UW symbols when the time-offset is t.
a_{ij;t} = sum_k s_{ijk;t} R(k)
b_{ijk;t} = a_{ij;t} a*_{ik;t}
c_{j-k;t} = sum_i b_{ijk;t}
d_{j-k;t} = abs(c_{j-k;t})^2
e_t = sum_j d_{j;t}
t_0 = argmax(e_t) =: FineTime

S_{ijk} = s_{ijk;t_0}
A_{ij} = a_{ij;t_0}
B_{ijk} = b_{ijk;t_0}
C_{j-k} = c_{j-k;t_0}
θ = argmax FFT(C_{j})
MediumFreq = θ/2/π * SymbolRate/p (ambiguity SymbolRate/p)

Strip the Medium Freq from the UW S, to give Ŝ. This forces Ŝ_{ijk} to have a phase that is independent of the j value (except for noise).
D_{ik} = sum_j Ŝ_{ijk}
E_{ijk} = D_{ij} D*_{ik}
F_{j-k} = sum_I E_{ijk}
φ = argmax FFT(F_{j})
CoarseFreq = φ/2/π*SymbolRate (ambiguity SymbolRate)

Use CoarseFreq to resolve the ambiguity in MediumFreq

Strip the ambiguity correction from the UW Ŝ, to give Š. This forces Š_{ijk} to have a phase that is independent of the j and k values.
G_i = sum_{jk} Š_{ijk}
ψ = argmax FFT(G_{i})
FineFreq = ψ/2/π * SymbolRate/q (ambiguity SymbolRate/q)

Use MediumFreq to resolve the ambiguity in FineFreq.

The phase and power may now be tracked using a moving average of the PS's, as they are fairly evenly spaced along the packet.

Background Distributions

Some estimates are needed that seem too hard to do using calculus. For these purposes, curve-fitting was applied to simple situations in Matlab.

Mean and Variance of the Power of a random Gaussian.

Let $z = 1+\sigma n$ be a complex random Gaussian with mean 1 and standard deviation σ^2. Then

$$\text{MeanPower}(\sigma^2) = \text{mean}(\text{abs}(z^2)) = 1+\sigma^2$$
$$\text{VarPower}(\sigma^2) = \text{var}(\text{abs}(z^2)) = 2\sigma^2 + \sigma^4$$

Estimating the maximum power of a set of complex Gaussians

Let $\{a_n\}$ be a collection of T complex Gaussians with zero mean and unit variance. Let the maximum power be $x = \max_n \text{abs}(a_n)^2$. Then x is a random real number. By curve-fitting in MATLAB, x has mean

$$\text{MeanMaxPower}(T) = 0.575+\log T + 3/(6T+1)$$

and variance

$$\text{VarMaxPower}(T) = 1.65 - 3T/(3T^2+2)$$

Loss of Power due to Frequency Offset

When N pilot symbols with a frequency offset f are summed coherently, the gain in power is

$$\text{IncoherentPowerLoss}(f) = \text{abs}(\text{mean\_n} \exp(jw(n)\, 2\pi f / F_{Sym}))^2,$$

where w(n) is the position of the nth PS within the packet. This has a maximum value of 1 when the frequency offset f is zero.

Estimating the probability of an FFT being roughly correct

Suppose T terms contribute to an FFT, each of the form $\exp(jn\,\theta) + \sigma\, m_n$, where m_n are complex Gaussian random numbers with unit variance. The FFT will have T independent values. The correct frequency will give a power of mean

$$\text{FFTcorrectMeanPower}(\sigma^2,T) = T^2\, \text{MeanPower}(\sigma^2/T)$$

and variance

$$\text{FFTcorrectVarPower}(\sigma^2,T) = T^4\, \text{VarPower}(\sigma^2/T)$$

The incorrect frequencies will yield, we assume, T-1 independent random complex numbers with interpolations. Each of the T-1 numbers has mean zero and variance

$$\text{FFTvariance} = T(1+\sigma^2).$$

Hence their mean power is

$$\text{FFTmeanPower} = T(1+\sigma^2)$$

and the variance in their power is

$$\text{FFTvarPower} = T^2(1+\sigma^2)^2.$$

The strongest of the incorrect frequencies will have power of mean

$$\text{FFTmeanMaxPower} = \text{FFTmeanPower} + \text{FFTvariance} * \text{MeanMaxPower}(T)$$

and variance

$$\text{FFTvarMaxPower} = \text{FFTmeanPower}^2 * \text{VarMaxPower}(T).$$

Therefore the correct frequency will be chosen, and θ will be roughly correct, with a safety margin of this many standard deviations :

$$\text{FFTcorrectSD}(T,\sigma^2) = (\text{FFTcorrectMeanPower} - \text{FFTmeanMaxPower}) / \text{sqrt}(\text{FFTcorrectVarPower}+\text{FFTvarMaxPower})$$

Estimating the variance of an estimated frequency

The variance of f, assuming the correct option emerges from the FFT, is

$$\text{FFTfreqVar}(T,\sigma^2) = F_{Sym}^2\, \sigma^2 / (6T^3)$$

Estimation of Variance, and Error Probabilities

Suppose the data has unit power and the AWGN has power σ^2.

We need the distribution of the estimate for the correct time offset, and also for the incorrect time offsets. I will use the notation $A \sim N(B,C)$ to mean that A is a random number with mean B and variance C. This is not necessarily Gaussian, although I will assume it is in order to get estimates. It will normally be clear from context whether a number is real or complex.

Estimation of Error Probability in Fine Time

At the correct fine time, with the correct UW, the variables will have the following distributions.

$S\_\{ijk\} \sim N(1,\sigma^2)$

$A\_\{ij\} \sim N(F, F\sigma^2)$ % with power loss

$B\_\{ijk\} \sim N(F^2, 2F^3\sigma^2 + CF^2\sigma^4)$

$C\_j \sim N(CF^2, 2CF^3\sigma^2 + CF^2\sigma^4)$

$D\_j \sim N(C^2F^2 + 2CF^3\sigma^2 + CF^2\sigma^4,$

$E \sim N(M_2(C^2F^2 + 2CF^3\sigma^2 + CF^2\sigma^4),$

At the wrong times, or with the wrong UW, the data and AWGN are indistinguishable.

$S\_\{ijk;t\} \sim N(0,1+\sigma^2)$

$A\_\{ij;t\} \sim N(0;F(1+\sigma^2))$
$B\_\{ijk;t\} \sim N(0\,, F^2(1+\sigma^2)^2)$
$C\_\{j;t\} \sim N(0\,,\, CF^2(1+\sigma^2)^2)$
$D\_\{j;t\} \sim N(CF^2\,(1+\sigma^2)^2\,,$
$E\_t \sim N(M_2\, CF^2\,(1+\sigma^2)^2\,,$
$\mathrm{Max}\, B \sim N(\;+(\log T + 0.57)\,, 1.65 *\,)$

Thus we might estimate the probability of error in terms of standard deviations (M1-m2)/sqrt(v1+v2)

The medium frequency is now stripped from the packet. Consider one medium group of PS, which contains M fine groups of F PS each. The first PS in each fine group should now be in phase, and can be added together coherently. The same applies to the second in each group, and so on. We can therefore use a similar procedure for finding the coarse frequency estimate that we did to find the medium frequency estimate. Although the variance of the coarse estimate is greater, its ambiguity is much greater again, and this can be used to correct the ambiguity in the medium frequency.

The probability of choosing the incorrect ambiguity depends on the variance of the Coarse and Medium Frequency estimates. It is this many standard deviations

Correct the UW for the adjusted Medium Frequency. Now all the PS within each medium group may be summed coherently. Each medium group yields a single value with quite low noise, of mean value MF and variance $MF\sigma^2$. These are spread evenly over the packet, and may be used to estimate the frequency with very low variance. The probability of choosing the wrong finest frequency is this many standard deviations, while the variance in the fine frequency is this much. The ambiguity in this estimate is the Symbol Rate divided by the spacing between medium groups.

Use the adjusted medium frequency to resolve the ambiguity in the Fine Frequency. The odds of picking the wrong ambiguity option are this many standard deviations. The variance in the frequency is this much.

To conclude, there are six sources of error in the procedure. The number of standard deviations that prevent each error is respectively :
Fine Time
Medium Freq wrong
Coarse Freq wrong
Medium/Coarse Ambiguity
Fine Freq wrong
Medium/Fine ambiguity

DSPACE PTY LTD

7 November 2002

PILOT SYMBOL PATTERNS IN COMMUNICATION SYSTEMS

FIELD OF THE INVENTION

This invention relates to signal processing in radio communications, in particular but not only to the use of pilot symbols in TDMA.

BACKGROUND TO THE INVENTION

The dominant method of TDMA packet acquisition uses blocks of pilot symbols, (Unique Words, UW), often coded with BPSK to allow identification of the packet's time offset. This provides poor frequency acquisition because all the pilot symbols are close together.

Two methods are commonly used to improve frequency resolution:

1. Pilot symbols spaced throughout the packet. Once the contiguous block of UW has been used to establish the packet's timing, the pilot symbols throughout the packet may be used to identify the frequency to a good resolution. This divides the UW into two parts, each used for different tasks. The proposed methods uses all pilot symbols for both time and frequency acquisition.
2. Two UWs placed at either end of the packet. The phase between the front and back pilot symbol UWs gives a very precise frequency estimate. However, it distinguishes poorly between certain frequency alternatives as no PS data is available throughout the bulk of the packet..

Differential decoding methods are comparatively fast and need not deal with coherence issues. However, they increase the effective SNR by multiplying noise data symbols together. To overcome this, differential decoding must be repeated at several different time-offsets, which increases the algorithm complexity. Further, it cannot improve on the frequency response of the pilot symbols.

Coherent correlation methods are comparatively fast but must be repeated for several different frequencies to ensure all symbols in the UW reinforce their sum, rather than cancelling. This repetition increases the complexity. Also, as before, the coherent correlation cannot do better than the frequency response of the chosen pattern of Pilot Symbols.

SUMMARY OF THE INVENTION

It is an object of the invention to improve the reliability of acquisition of a data packet in noise, or with a smaller cost in pilot symbols, or over a broader bandwidth, or a combination of these, compared with the prior art. Or at least to provide a useful alternative to existing systems involving pilot systems.